# Best Practices and Metrics for Virtual Reality User Interfaces

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## Abstract

Virtual Reality (VR) technology has become increasingly effective and accessible within the past decade [15]. With this increase in the technology's prevalence and cultural significance, certain interaction techniques and design choices have emerged as the most widely used and recommended. This research effort employs a VR experiment in which multiple selection methods, interface placements, and navigation techniques are compared side-by-side, and performance metrics and preference data are collected. Both best practice and to-be-avoided methods are examined, and the performance and preference data is analyzed. Determinations made based on the data gathered are partly in-line with expectations according to best practices, partly inconclusive, and partly contrary to the expected performance and preference results. Results suggest that virtual laser pointers and tapping are equally recommendable selection methods for most VR experiences, hand-mounted menus produce the best results overall, and despite performance advantages, joystick navigation should be avoided in VR due to user comfort concerns.

# Acknowledgements

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# Contents

# 1 Introduction

The term *virtual reality* was coined in 1989 by Jaron Lanier, CEO of VPL Research, LLC [62]. The term is sometimes used interchangeably with *virtual environment*, which would include any program with a 3D component [71]. A more restrictive definition requires the use of a stereoscopic display, fully substituting the user's visual percepts, and often incorporates input devices for affecting the virtual environment [15]. This paper subscribes to the latter definition.

VR technology of the kind in use today originated as early as the late 1960s [66]. A head-mounted display is used to give the user the impression, at the very least a visual impression, that they are in an alternate space, a virtual reality. By the mid 1980s, improvements in tracking technologies led to the development of various virtually representable input devices, such as the VPL DataGlove [63]. These input devices further allowed users to not only witness the virtual environment, but to affect it.

After a falloff of VR development and experimentation by the early 2000s, credited largely to the bulkiness of the technology and the cost barrier at the time [15], a new generation of VR headsets has been developed and released throughout the 2010s. Among the most popular are the headsets in the Oculus series: DK1 (2013), DK2 (2014), Rift (2016), and more recently the Oculus Go (2018), Rift S (2019), and Quest (2019). The early Oculus models did not include tracked, virtually represented input devices, and were even bundled with the XBox 360 controller [42]. However, the Oculus Touch controllers were introduced later in the same year as the Rift release [22]. Another popular headset is HTC's Vive, which debuted with motion controllers in 2015, and was later followed by a Pro model in 2018 and the Vive Cosmos in 2019 [35]. Lastly, Sony's popular PlayStation VR headset, released in 2016, is marketed both for use with a traditional video game controller and with the PlayStation Move Motion Controllers [59].

The availability of systems such as these is contributing to the significant increase in developer and consumer participation in VR, witnessed in the past five to seven years [15]. Along with this increase in participation, research, industry examples and developer guidelines have built up to solidify the interaction techniques and design methodologies that are widely accepted as best practice. This paper focuses on three specific areas of VR user interfaces in which best practices have been made evident in the industry: selection methods, menu placement, and player navigation. This research conducts an experiment in which best practices in these areas are compared with alternative methods, including some widely considered as to-be-avoided methods.

This experiment compares differences between methods using two major areas of consideration: performance and preference. Hypotheses are stated according to expected results based on best practices, and the data gathered in the experiment is statistically evaluated to examine the validity of each hypothesis.

The following section will review and define the best practices that are examined in this research effort.

# 2 Best Practices

The best practices, or industry-recommended methods and considerations, in this section are gathered from and validated by multiple types of sources. Research papers and academic articles are referenced when available, and commercial developer guides and examples from the industry are supplied as supplemental evidence. This is not a comprehensive review of all VR best practices to date, but rather an outline of the methods selected for study in this research.

## 2.1 Selection Methods

Graphical user interfaces (GUIs) were first developed by Xerox Palo Alto Research Center in the 1970s and were popularized by Apple's breakthrough personal computers in the following decade [76], forming the basis of nearly all human-computer interactions today. In the development of 3D virtual environments, a common approach in achieving user interaction has been to mimic these 2D GUIs to which most users are accustomed. One of the most common interfaces for system control and selection, in traditional computer interfaces and VR alike, is menus [8], and specifically the selection of buttons that are tied to individual actions. The experiment outlined in this paper, therefore, compares selection methods based on the completion of prompted tasks, completed by interacting with virtual menus.

Several different selection methods have been utilized in both research and commercial VR implementations, incorporating different types of input devices. One of the most popular selection methods that was *not* examined in this research is gaze selection [20, 23, 78]. With this method, a pointer follows the user's view like crosshairs, and selections are made by gazing at the desired object and hovering for some set time. This method is useful for headsets that do not incorporate a hand-held controller. Another significant method that was not examined in this paper is gesture control, which often incorporates a glove input device [8, 46, 63] or alternatively, more recently, infrared sensing of hand position and orientation [68].

Due to the popularity of the headsets listed in the Introduction, and their unanimous use of controllers (both VR-specific and traditional), gaze selection and gesture control are significantly less widespread as selection methods in VR today. Thus, the best practice selection methods compared in this research are the most common selection methods implemented with controllers: laser pointer selection, "tapping", and directional-pad selection.

### 2.1.1 Virtual Laser Pointer

The virtual laser pointer, or "flashlight", or "wand", has been utilized in VR interfaces since at least the 1980s [11, 57]. An early description of the technique is as follows: "Physically, the wand is a spatial position and orientation sensor on a handheld stick. In software, the wand emanates a ray which can be used for pointing at virtual objects." [12] The basic concept remains much the same today, though the "sensor on a stick" we now know as a controller.

As recently as 2014, the virtual laser pointer technique has been discouraged by researchers for two main reasons: the method is not a natural way of interacting with objects, and previously the technology did not provide adequate accuracy and stability for the technique to be viable [33]. The latter concern has been remedied by the quality of modern headsets and tracking technology.

The first concern, however, that in order to maintain immersion, VR interfaces should be "natural" and not follow the Windows, Icons, Menus, Pointer metaphor, has been often asserted since the early 1990s [51]. Bowman and Wingrave provide an alternative to this view. They propose that naturalism should only be applied when realism is the chief goal; if efficiency of task completion is the goal, "the interface should be constructed so as to minimize time and errors – such an interface may not be natural. [8]"

The current prevalence of virtual laser pointers in both research and commercial VR software suggests that the benefits outweigh the concerns. Many recent VR researchers have chosen the laser pointer interaction method as the primary mechanism in their research [27, 53, 61, 80], and examples of virtual laser pointer interfaces are plentiful in the industry, both from developer toolkits [4, 73] and in published experiences [5, 29, 50].

The two main justifications for the virtual laser pointer method are its simplicity, and the ease of use resulting from not requiring the user to extend or reach uncomfortably to interact with objects outside of the immediate area [42].

### 2.1.2 Tapping

Tapping, or reach-out-and-touch selection, was popularized by the various "goggles and gloves" VR models of the late 1980s and early 1990s [62, 63, 71]. Tapping for selection, along with the corresponding manipulation technique of grabbing, is widely considered one the most immersive interaction methods because these techniques most accurately reassemble real-world, natural interactions [33]. Simply, interactable virtual objects are treated, within the confines of the technology, like interactable objects in reality.

Due to the compelling nature of this design, tapping and grabbing of virtual objects has been the focus of VR demonstrations since the release of the earliest systems [2] and has remained a focus in recent demonstrations [74].

Like the virtual laser pointer technique, the prevalence of tapping (and grabbing) in VR user interfaces is evidenced by the method's appearances in VR research [8, 19, 25, 27], developer guides and toolkits [4, 73], and industry examples [5, 29, 39, 41].

### 2.1.3 Directional-pad Selection

The final selection method, directional-pad (d-pad) selection, did not originate in VR and remains in use today mostly in computing and gaming interfaces not specific to VR. It is by far the oldest selection technique in human-computer interfaces as we know them today, as it originated in its first form along with the advent of the terminal in the 1960s [31]. Much like modern keyboards, keyboards attached to the first terminals included directional buttons: an up, down, left, and right arrow. Selections could be made by using the directional buttons to change which item on the screen is highlighted, and then selecting a confirmation key, often the return key, when the option highlighted is the desired selection.

This method made its debut in the video game world with the release of the Nintendo Entertainment System (NES) in 1983, which featured the industry's first "gamepad", which included a cross-shaped directional pad [77]. Since this release, most major video game console controllers have featured a d-pad, including the recent and notable PlayStation 4 controller [60], Xbox 360 and Xbox One controllers [49], and Steam Controller [72].

For early adoption of the new wave of VR headsets throughout the 2010s, headsets were shipped with simple controllers (single-hand, non-tracked, d-pad with few buttons) such as the controller originally paired with the Oculus Rift and now supporting Samsung's Gear VR [20]. Headsets were also made compatible with games that only supported non-VR controllers, resulting in marketing and support for parings such as the PlayStation 4 controller with the PlayStation VR headset [59] and the Xbox 360 controller with the Oculus Rift and HTC Vive [42].

It was through simple controllers and support for existing video game controllers that the traditional d-pad selection technique has been popularized in VR, and it is for this reason that the technique is examined alongside the other two methods in this research effort.

## 2.2 Menu Placement

The second area of best practice included in this paper's evaluation concerns the placement of 2D menus in their 3D virtual environment. There exist three options for menu placement in VR, and because of this limited number of options, all three choices were implemented and examined in this research. Two of the menu placement types, world space and arm or hand-mounted, can be considered best practice and are seen in research and industry examples. The third option, heads-up displays, though promising for diegetic interfaces in which interface elements exist in the narrative of the virtual world, are increasingly less recommended by researchers and developers alike.

### 2.2.1 World Space Menus

World space or world-anchored menus utilize the simplest and most common menu placement in VR [56]. The menu is fixed in the virtual environment and does not change position in response to the user's gaze or indirect controller motions. Thus, with this menu placement, the virtual environment is an extension of how users understand and utilize 2D menus in normal life, leading to increased familiarity, usability and productivity [1]. Additionally, menus of this type are required when using a headset without a controller, with an implementation of gaze selection, for example.

Evidencing the prevalence of world space menus in VR, world space menus and UI widgets are natively supported by the major VR development engines, Unreal Engine 4 [18] and Unity [69]. VR researchers utilize world space menus in their experiments [27, 53, 61, 78, 80]. Experts recommend world space menu placement [33, 42], and numerous industry examples show the use of world space menus [5, 39, 41, 50, 74].

There are, of course, usability and comfort considerations when designing world space menus [1, 13]:

- The menu should be easily within reach if the interaction technique requires touch.
- The menu should not be closer than half a meter or farther than 20 meters, regardless of interaction method.
- The menu should be in view, or within ergonomic constraints for comfortable head rotation.
- Text should be adequately large for readability.

These usability and comfort guidelines were followed in the experiment implementation for this research effort.

### 2.2.2 Hand-mounted Menus

Hand-mounted menus originated with the development of the glove and "pen-and-tablet" input devices of the 1990s. Some glove input devices, such as the DataGlove, contained system control buttons that were built onto the top of the forearm portion of the device and were represented virtually for in-experience use [63]. Other glove input devices, such as the Pinch Glove [8], provided menu selections based on hand gestures, pinching with a specific finger to select an option on the menu.

Pen-and-tablet input devices were implemented by several researchers throughout the 1990s [3, 6, 7, 26]. These were, in most cases, a physical panel with a handle, to be held by the user, on which virtual menu items would be placed and could be interacted with using a pen device in the opposite hand. Even with these early models, hand-held menus were shown to provide increased precision over world-fixed menus [3, 6].

These dated examples of input devices and hand-mounted menus have been reworked utilizing controllers of modern VR headsets. One influential example of this is Google's Tilt Brush [29]. This experience was released alongside and with support for the HTC Vive in April 2016 and was, therefore, one of the earliest new-generation VR games backed by a major company. In Tilt Brush, multiple menu panels, or palettes, are attached to one hand's controller, and the user can rearrange the menu components and interact with the menus using a virtual laser pointer on the opposite-hand controller. Similar hand-held, palette-style menus can also be seen in later-released experiences [14, 21, 30]. Hand-mounted menu designs using the latest technologies have been implemented and discussed by multiple researchers [1, 38, 54, 64].

### 2.2.3 Heads-up Display

The term *heads-up display* (HUD) originated in the aircraft industry to describe information and controls that a pilot can interact with while maintaining a view forward, not needing to look down at an instrument panel. The term HUD has been adopted in other industries to describe information or menus that follow the user's view, as if attached to a visor on a helmet [44]. Virtual HUDs have been implemented as menus in VR since the mid 1990s [75].

The general consensus, however, is that this sort of interface in VR, due to the method being unnatural, is "likely to break the sense of immersion." [44] A notable exception is afforded in cases where a HUD interface appears within the narrative of the experience: when the player character in a game is wearing a helmet that utilizes a HUD, for example. This case is treated differently because it incorporates a diegetic user interface, which counteracts the loss of presence by specifically designing the HUD to be part of the environment in which the user is being immersed [54].

Breaking the user's sense of immersion is not the only negative aspect to utilizing HUD interfaces in VR, however. Even if the interface is incorporated into the narrative of the experience, it may still be necessary to ignore guidelines on how close an interface should be to the user's eyes in order to ensure comfort. To achieve the effect of a visor, for example, the interface must be closer than the recommended half meter [1].

To maximize comfort, the HUD implemented in this experiment is not a diegetic interface, and instead follows comfort guidelines to ensure readability.

## 2.3 Player Navigation

Player navigation, or locomotion or travel, in VR, more than any other design aspect, prioritizes usability and comfort over efficiency. This is due to the documented possibility of cybersickness (cold sweating, nausea) [47]. Cybersickness is believed to be caused by any conflict between inputs of two or more sensory systems [40]. The most common sensory conflict in VR is between the user's visual system and their vestibular system (seeing movement without feeling it in their inner ear), which occurs most extremely when performing traditional forms of virtual locomotion, such as joystick navigation [42].

The most common method that does not have the concern of sensory conflict is teleportation [42]. This research effort compares teleportation and joystick navigation to validate the difference in reported cybersickness, while comparing users' preference and efficiency with each method.

### 2.3.1 Joystick Navigation

Traditionally, the most common navigation method in 3D virtual environments is the use of a joystick or directional pad, often utilizing another joystick or a mouse to change the player's view [42]. While a very simple system, and a method many users are accustomed to through use of other applications, joystick navigation in VR causes the most common sensory mismatch: the virtual player moves smoothly across the virtual environment while the user remains standing or sitting in place. Because of this conflict and the potential for users to experience cybersickness, joystick navigation is not recommended by experts [24].

This method is further complicated by the need for reorientation. As mentioned, this is traditionally done by controlling the player's view using an additional joystick or mouse. However, affecting the user's view in this way in VR "does not yield correct vestibular cues" [24] and, therefore, leads to cybersickness. This can be avoided by not including a means for the user to affect their viewpoint, other than the simple movement of their head. However, if the experience requires the user to be able to rotate beyond what is comfortable, reorientation cannot be avoided. It has been shown that implementing "viewpoint snapping" significantly lessens feelings of cybersickness during reorientation [24], so a form of viewpoint snapping was implemented in this experiment to address this issue.

### 2.3.2 Teleportation

Teleportation, sometimes called infinite velocity travel or "jumping", has been implemented and tested as a navigation technique in 3D virtual environments, appearing very early in the existence of VR [9].

Like virtual laser pointers, some professional recommendations do not align with the prevalence of the technique in the industry. Research has shown that teleportation results in higher reported disorientation when compared to joystick navigation [9], and because of this, experts suggest avoiding the use of teleportation and to instead "provide smooth transitional movements between locations." [33]

Again, like virtual laser pointers, teleportation is used broadly across the industry despite some professional recommendations. Teleporting is built-in functionality in the major development libraries and toolkits [4, 73], is recommended in developer guides and documentation [28, 45, 79], and can be seen in numerous published experiences [17, 34, 36, 37, 52, 65].

# 3 Hypotheses

With the outlined best practices in mind, six hypotheses were developed that describe expected results. The experiment and analysis in this research effort were conducted with the goal of validating or rejecting these hypotheses.

1. **Beginners will be best with and prefer either tapping or d-pad selection.**

Participants new to VR will likely be least skilled with virtual laser pointer selection, compared to the other two selection methods. Tapping has the advantage of being the most natural method, and d-pad selection is a method users will have likely encountered in other applications. Additionally, the precision required for the virtual laser pointer method may not come quickly to users learning it for the first time.

2. **Experienced users will be best with and prefer the virtual laser pointer for selection.**

Based on the virtual laser pointer's prevalence in the industry, users who have experienced VR prior to the experiment almost certainly will have interacted with a virtual laser pointer selection system. It is expected that this familiarity will help counteract any downsides of the method and result in improved performance.

3. **Users as a whole will be best with and prefer world space and hand-mounted menus over heads-up displays.**

Due to comfort and usability concerns, it is expected that heads-up displays will rank last among menu placements.

4. **Beginners will be best with and prefer joystick navigation.**

It is expected that most users unfamiliar with VR will have experience with more traditional 3D environment navigation techniques, the foremost being joystick navigation. Beginners will likely have no experience with a navigation system based on teleportation.

5. **Experienced users will be best with and prefer teleporting.**

Familiar with teleporting in VR, experienced users will likely be able to take advantage of the potential for quicker navigation, with less susceptibility for disorientation.

6. **Joystick navigation will cause significantly more feelings of sickness than teleporting.**

This hypothesis is based on the literature claiming the main cause of cybersickness is a mismatch in sensory inputs.

# 4 Methodology

This research compares selection methods, menu placements, and navigation techniques by gathering performance and preference data from users that complete the VR experiment.

## 4.1 Performance

The performance metrics for each area of focus are compiled through task completion, in which similar or identical tasks are completed using each different method. This follows the process of other researchers comparing interface types in VR [8, 43, 55]. All methods are compared based on task completion times, and selection methods and menu placements are additionally compared on the basis of accuracy, negatively evaluated as the number of mistakes made. This, again, is according to patterns outlined in the papers referenced above.

## 4.2 Preference

User preference data is obtained through the Self-Assessment Manikin (SAM) model [10] in which users report feelings of pleasure, arousal, and dominance, pertaining to each interaction technique and menu placement. This is a standard method of measuring emotion and has been used similarly in other VR research [58].

Each aspect of reported emotion is rated on a 9-point scale, a variation of the standard 5-point SAM scale which allows for increased precision. In accordance with the standard SAM, pleasure is measured on a scale with “Unhappy” on one extreme and “Happy” on the other, and arousal is measured between “Calm” and “Excited”. Dominance is typically measured on a scale from “In Control” to “Controlled”, but the latter was altered in this research to be “Not In Control”, to more clearly pertain to user interfaces. The middle of the scale is always denoted as “Neutral”.

Lastly, users’ feelings of sickness in VR (encompassing both dizziness and nausea) have been recorded in other research as a means to compare VR user interfaces [8]. Comfort is reported in this experiment using the same scale method as the three SAM features, in this case using a scale from “Comfortable” to “Sick”.

# 5 Implementation

The VR experience described in this section was developed in the Unity game engine [70] utilizing the SteamVR library [73] and several other resources from the Unity Asset Store [16, 32, 48, 67]. The experience was developed and run on a Windows 10 machine with an Nvidia GTX 1070 graphics card, Intel Core i7-5820K, and 16 gigabytes of RAM. The VR headset used was the original HTC Vive, along with the Vive Deluxe Audio Strap.

## 5.1 Pre-experiment Questions

The experiment is set in a plain, white room and begins with slowly pulsing text reading, “Pull a trigger to get started...” Once the user pulls a controller trigger, the pre-experiment dialog sequence begins. A dialog template was utilized for consistent style and interaction throughout the experience.

The user is thanked and instructed to use the laser pointer to select options in the upcoming dialogs. The user then specifies their experience level in VR (see Figure 1) and their dominant hand. The experience level is used to separate the results into groups in the analysis phase, and the experiment components are adjusted according to the user's selected dominant hand.


Figure 1: Pre-experiment question using dialog template.

## 5.2 Skill Test

The Skill Test consists of three "tests" to allow the participant to become comfortable before beginning the experiment. The tests are throwing darts at a dart board, passing balls shot toward the user through a hand-held hoop, and entering displayed number sequences using the virtual laser pointer and a world space number pad menu.

The Skill Test offers a gamified experience for the user, making their participation more enjoyable. Additionally, the tests provide metrics with which a baseline skill score can be calculated for each user. This baseline skill score was intended to be used in normalization of the experiment performance data. The intent was that such an adjustment might lessen the effect of per-user factors such as natural coordination and varying levels of intelligence. The data adjusted according to this baseline skill score was not used in final analysis. Details on this are outlined in the Data Analysis section.


Figure 2: Skill Test #1 - throwing darts.

## 5.3 Experiment: Part 1

Part 1 of the experiment is introduced with instructions on the dialog template. The user is informed that they will be prompted to enter a series of number or letter sequences, displayed in front of them, using the indicated selection method and the menu available. Each selection method (virtual laser pointer,


Figure 3: Number sequence, world space menu, tapping selection.

tapping, d-pad selection) is introduced, and the opportunity is given for the user to try each method.

The virtual laser pointer method requires the user to hover the pointer on the desired button and pull the controller trigger to make a selection. The tapping method requires the user to touch the button with the controller, and, again, pull the trigger to make a selection. Lastly, the d-pad selection method requires the user to change the highlighted button in view by pressing directions on the controller thumb-pad, and again pulling the trigger to make a selection. The user is then required to enter each sequence displayed using a different combination of selection technique and menu placement. The six sequences use the following combinations:

1. Number sequence, world space menu, tapping selection (Figure 3).
2. Letter sequence, heads-up display, virtual laser pointer (Figure 4).
3. Number sequence, hand-mounted menu, tapping selection.
4. Letter sequence, world space menu, d-pad selection (Figure 5).
5. Letter sequence, hand-mounted menu, virtual laser pointer.
6. Number sequence, heads-up display, d-pad selection.

Figure 4: Letter sequence, heads-up display, virtual laser pointer.


Figure 5: Letter sequence, world space menu, d-pad selection.

The time each user takes to complete each sequence is recorded, along with the number of mistakes the user makes entering each sequence. These results are used to examine the performance aspects of Hypotheses 1-3.

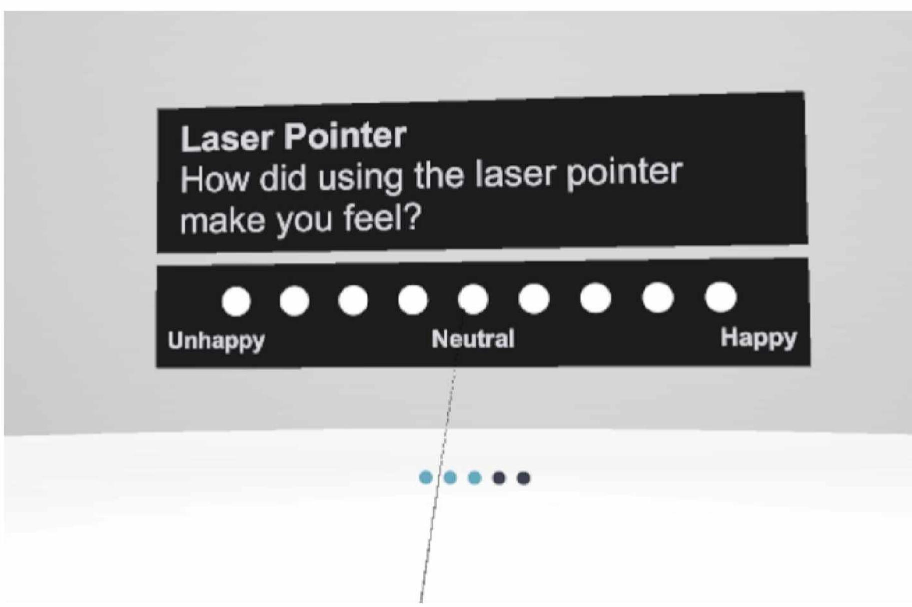


Figure 6: Pleasure SAM dialog for virtual laser pointer.

For the preference aspects of the hypotheses, the tests are followed by SAM dialogs (see Figure 6). The user is asked to report their feelings of pleasure (happiness), arousal (excitement), and dominance (control) for each selection method and menu placement.

## 5.4 Experiment: Part 2

Part 2 of the experiment again begins with introduction and instruction. The user is informed the next test involves player navigation and is given the opportunity to try the two navigation techniques: joystick navigation and teleporting. The user is also required to use the viewpoint snapping feature before continuing, as the final test will require reorientation.

Joystick navigation in the experiment utilizes the user's thumb position on the left thumb-pad, and the player position is affected by this 2D input, simulating an analog stick. Teleporting in the experiment is achieved by pressing down on the left thumb-pad and releasing when the teleport indicator is on a valid location. Viewpoint snapping uses the right thumb-pad; pressing on the left half will snap the user's view 20 degrees to the left, and pressing on the right half will snap the user's view 20 degrees to the right.

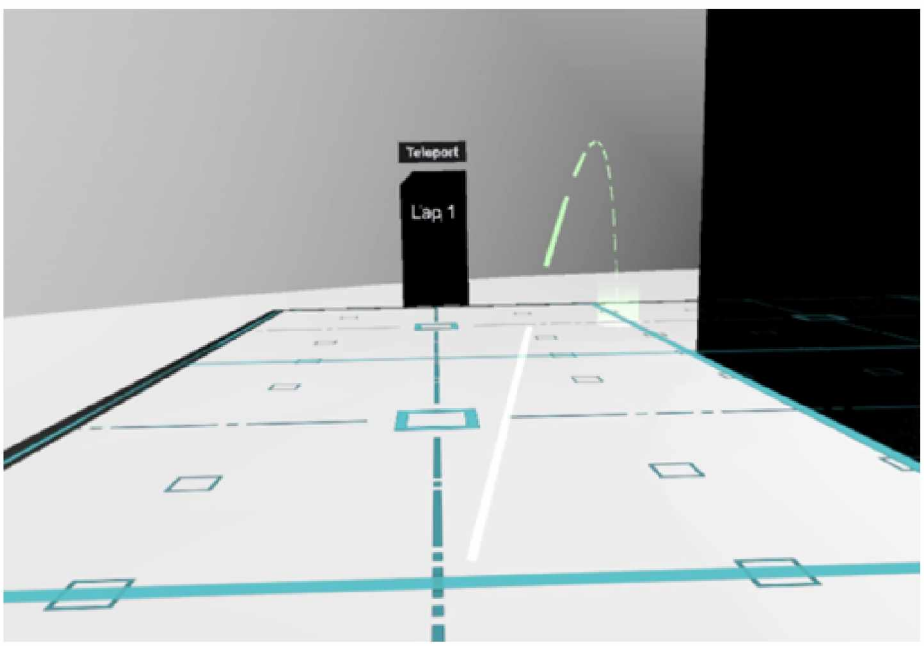


Figure 7: Navigating a lap with teleportation.

After the two navigation techniques and viewpoint snapping are introduced, the user is instructed that they will complete three laps on a simple course. The first lap includes no obstacle walls, the second lap includes three, and the final lap includes nine. Completion times are recorded by lap, and preference data is gathered after test completion. Along with the pleasure, arousal, and dominance scales, a comfort scale is also included for navigation techniques.

After completing the SAM dialogs, the user is thanked and instructed to remove the headset.

# 6 Data Analysis

Data was gathered from 50 participants over the course of five sessions. Of these, 21 users reported themselves VR "first timers", 21 said they had "tried it before", two said they were "skilled", and four claimed to be "seasoned veterans." Thus, for Hypotheses 1, 2, 4, and 5, the 21 first timers were classified as "beginners," and the remaining 29 results were classified as from "experienced users."

While no hypotheses rely on comparing the results from these two user groups with each other, analysis revealed interesting differences. The resulting differences in performance and preference, comparing beginners and experienced users, are shown in Appendix A.

## 6.1 Testing Hypotheses

All hypotheses are examined using difference-of-means analysis. The null hypothesis in each case states that the means being compared are equal. A two-sample t-Test is used to determine whether the null hypothesis can be rejected and it can be determined that a significant difference exists between the two metrics. The two-tail $p$ value is evaluated for greater statistical assurance. According to standard practice, if the $p$ value is less than 0.05, the null hypothesis is rejected and the difference is considered significant. This analysis approach follows patterns seen in other similar research involving VR user interfaces [43].

Before the t-Test, a two-sample F-Test is done to determine the difference in the variances of each metric. If the larger variance is less than two times the smaller, the subsequent t-Test is completed assuming equal variance, and a pooled variance (average of the two) is utilized. Otherwise, the t-Test is completed assuming unequal variances.

## 6.2 Outliers

To improve the validity of the tests, all F-Tests and t-Tests are completed excluding outliers. Outliers are determined using the quartile method. The first and third quartile are calculated, and the resulting difference is the inner-quartile range (IQR). If a value is 1.5 times the IQR less than the first quartile value, it is flagged as an outlier on the low end. Similarly, if a value is 1.5 times the IQR more than the third quartile value, it is an outlier on the high end.

### 6.3 Evaluating Preference

As described above, the Self-Assessment Manikin model was utilized to allow participants to report their feelings of pleasure, arousal, and dominance [10]. In comparing preference of interaction methods and menu placements, only ratings of pleasure (happiness) and dominance (control) were considered. These two ratings have clear positive and negative extremes in the context of user interfaces, while calmness or excitement may be interpreted as either positive or negative.

### 6.4 Skill Test Data

As mentioned in the Implementation section, the Skill Test portion of the VR experience was partly intended to provide a baseline skill score with which experiment data might be adjusted to, in theory, lessen the effects of factors such as natural coordination or a user's ability to learn quickly. Simply, participants who did best in the Skill Test would have their experiment performance dampened, and data from users who performed worst in the Skill Test would be adjusted for improvement.

After adjusting the performance data, using a composite skill score based on z-scores, the resulting data contained a higher number of outliers and had greater variance than the original performance data. For this reason, the adjusted data was discarded, and this approach was not used in the final analysis.

## 7 Findings

Performance and preference results were evaluated using the process described above. The results are reported here according to each hypothesis.

### 7.1 Hypothesis 1

**Beginners will be best with and prefer either tapping or d-pad selection.**

Results of this study are **inconclusive** for this hypothesis on the basis of both performance and preference. Beginners had the worst performance times with d-pad selection, yet times with tapping were not significantly different than times with the laser pointer. Beginners made the most mistakes with tapping, but the amount of mistakes made with d-pad selection was not significantly different from mistakes with the laser pointer. Finally, beginners were least happy with d-pad selection yet reported no difference in happiness or sense of control between laser pointer and tapping. See Appendix B.1 for detailed results.

**Summary of results:**

- There was no significant difference in beginners' performance times comparing virtual laser pointer selection and tapping ($t = 1.812$; $p = 0.075$).

- Beginners were significantly slower with d-pad selection, compared to the other two selection methods: virtual laser pointer ($t$ = 5.251; $p < 0.001$), tapping ($t$ = 6.312; $p < 0.001$).
- Beginners made significantly more mistakes with tapping than the other two selection methods: virtual laser pointer ($t$ = 2.505; $p$ = 0.018), d-pad ($t$ = 2.542; $p$ = 0.017).
- There was no significant difference in mistakes made comparing laser pointer and d-pad selection ($t$ = 0.081; $p$ = 0.936).
- There was no significant difference in feelings of happiness comparing laser pointer and tapping ($t$ = 0.318; $p$ = 0.752).
- Beginners were significantly less happy using d-pad selection, compared to the other two selection methods: virtual laser pointer ($t$ = -2.807; $p$ = 0.008), tapping ($t$ = -2.231; $p$ = 0.031).
- There was no significant difference in feelings of control comparing laser pointer and tapping ($t$ = -1.922; $p$ = 0.062) and comparing laser pointer and d-pad selection ($t$ = 1.352; $p$ = 0.184).
- Beginner's felt significantly more in control when using tapping for selection, compared to d-pad selection ($t$ = 3.394; $p$ = 0.002).

## 7.2 Hypothesis 2

**Experienced users will be best with and prefer the virtual laser pointer for selection.**

Results of this study **reject** this hypothesis on the basis of performance and are **inconclusive** on the basis of preference. Experienced users did not perform significantly faster with the laser pointer when compared to tapping. Experienced users made more mistakes with the laser pointer than with d-pad selection. Finally, experienced users were no happier with the laser pointer than with tapping and reported no difference in feelings of control between any of the three selection methods. See Appendix B.2 for detailed results.

**Summary of results:**

- There was no significant difference in experienced users' performance times comparing virtual laser pointer selection and tapping ($t$ = 0.395; $p$ = 0.694).
- Experienced users were significantly slower with d-pad selection, compared to the other two selection methods: virtual laser pointer ($t$ = 2.725; $p$ = 0.007), tapping ($t$ = 2.564; $p$ = 0.012).
- There was no significant difference in mistakes made comparing laser pointer and tapping ($t$ = 1.858; $p$ = 0.068).

- Experienced users made significantly less mistakes with d-pad selection than the other two selection methods: virtual laser pointer ($t$ = -4.766; $p < 0.001$), tapping ($t$ = -4.666; $p < 0.001$).
- There was no significant difference in feelings of happiness comparing laser pointer and tapping ($t = 0.384$; $p = 0.703$).
- Experienced users were significantly less happy using d-pad selection, compared to the other two selection methods: virtual laser pointer ($t$ = -3.790; $p < 0.001$), tapping ($t$ = -3.597; $p < 0.001$).
- There was no significant difference in feelings of control between any of the selection methods: laser pointer and tapping ($t$ = -1.118; $p = 0.268$), laser pointer and d-pad selection ($t = 0.598$; $p = 0.552$), tapping and d-pad selection ($t = 1.748$; $p = 0.086$).

## 7.3 Hypothesis 3

**Users as a whole will be best with and prefer world space and hand-mounted menus over heads-up displays.**

Results of this study **reject** this hypothesis on the basis of performance but **confirm** the hypothesis on the basis of preference. World space menus resulted in the worst performance times. There was not a significant difference in mistakes made with hand-mounted menus and heads-up displays. Interestingly, users were least happy and felt the least in control when using heads-up displays. See Appendix B.3 for detailed results.

**Summary of results:**

- Users were significantly slower with world space menus, compared to the other two menu placements: hand-mounted menus ($t = 3.894$; $p < 0.001$), heads-up display ($t = 3.141$; $p < 0.002$).
- There was no significant difference in performance times comparing hand-mounted menus and heads-up displays ($t$ = -0.990; $p = 0.323$).
- Users made significantly less mistakes with hand-mounted menus compared to the other two menu placements: world space ($t$ = -4.332; $p < 0.001$), heads-up display ($t$ = -4.939; $p < 0.001$).
- There was no significant difference in mistakes made comparing world space menus and heads-up displays ($t = 0.148$; $p = 0.883$).
- There was no significant difference in feelings of happiness comparing world space menus and hand-mounted menus ($t$ = -0.710; $p = 0.479$).
- Users were significantly less happy using heads-up displays, compared to the other two menu placements: world space menus ($t$ = -4.583; $p < 0.001$), hand-mounted menus ($t$ = -5.018; $p < 0.001$).

- There was no significant difference in feelings of control comparing world space and hand-mounted menus ($t$ = 1.870; $p$ = 0.065).
- Users felt least in control using heads-up displays: compared with world space menus ($t$ = -7.853; $p < 0.001$), compared with hand-mounted menus ($t$ = -5.903; $p < 0.001$).

## 7.4 Hypothesis 4

**Beginners will be best with and prefer joystick navigation.**

Results of this study **confirm** this hypothesis on the basis of performance but **reject** the hypothesis on the basis of preference. Beginners had the best performance times with joystick navigation. However, beginners were happier when teleporting and reported no difference in sense of control when comparing the navigation techniques. See Appendix B.4 for detailed results.

**Summary of results:**

- Beginners were significantly faster with joystick navigation ($t$ = -4.781; $p <$ 0.001).
- Beginners were significantly happier when teleporting ($t$ = 3.604; $p$ = 0.001).
- There was no significant difference in feelings of control comparing the navigation techniques ($t$ = -1.582; $p$ = 0.124).

## 7.5 Hypothesis 5

**Experienced users will be best with and prefer teleportation.**

Results of this study **reject** this hypothesis on the basis of performance but **confirm** the hypothesis on the basis of preference. Experienced users had the best performance times with joystick navigation. However, experienced users were happier when teleporting and reported no difference in sense of control when comparing the navigation techniques. See Appendix B.5 for detailed results.

**Summary of results:**

- Experienced users were significantly faster with joystick navigation ($t$ = -3.191; $p$ = 0.002).
- Experienced users were significantly happier when teleporting ($t$ = 2.194; $p$ = 0.033).
- There was no significant difference in feelings of control comparing the navigation techniques ($t$ = -1.793; $p$ = 0.079).

### 7.6 Hypothesis 6

**Joystick navigation will cause significantly more feelings of sickness than teleporting.**

Results of this study **confirm** this hypothesis. Users overall reported higher comfort using teleportation. See Appendix B.6 for detailed results.

**Summary of results:**

- Users were significantly less comfortable using joystick navigation ($t$ = -3.479; $p = 0.001$).

## 8 Conclusion

The results of this research suggest there may be no definitively correct selection method for every VR experience. For most cases, the results here show that either virtual laser pointer selection or tapping are preferable above d-pad selection. However, if accuracy is the highest priority, d-pad selection is the clear choice. Concerning menu placement, hand-mounted menus produced the best results overall, despite being less common than world space menus. Lastly, these results seem to require developers to choose between greater navigational efficacy (joystick) and user comfort (teleportation). Because the performance difference between navigation techniques was significant yet not drastic, user comfort should be prioritized, and joystick navigation should be avoided in VR.

## Appendix A Beginners vs. Experienced Users

All results below are calculated excluding outliers identified with the standard quartile method.

### A.1 Summary of Results

- Beginners significantly slower with d-pad selection ($t = 2.592$; $p = 0.011$).
- Experienced users made significantly more mistakes with the virtual laser pointer ($t$ = -4.521; $p < 0.001$) and tapping ($t$ = -2.145; $p = 0.035$).
- Experienced users significantly faster with teleporting ($t = 3.304$; $p = 0.002$).
- Beginners significantly happier when teleporting ($t = 2.036$; $p = 0.048$).

## A.2 Performance

### Performance Times by Selection Type

| Selection Type | Beginners | Experienced Users |
|---|---|---|
| Laser Pointer | $m$=13.19s, $sd$=4.25 | $m$=13.09s, $sd$=4.63 |
| Tapping | $m$=11.27s, $sd$=4.40 | $m$=12.65s, $sd$=6.39 |
| D-pad | $m$=18.86s, $sd$=5.28 | $m$=15.82s, $sd$=5.88 |

- No significant difference in performance times with virtual laser pointer ($t$ = 0.105; $p$ = 0.917) or tapping ($t$ = -1.097; $p$ = 0.276).
- Beginners significantly slower with d-pad selection ($t$ = 2.592; $p$ = 0.011).

### Mistakes Made by Selection Type

| Selection Type | Beginners | Experienced Users |
|---|---|---|
| Laser Pointer | $m$=0.03, $sd$=0.17 | $m$=0.47, $sd$=0.69 |
| Tapping | $m$=0.37, $sd$=0.69 | $m$=0.84, $sd$=1.16 |
| D-pad | $m$=0.03, $sd$=0.16 | $m$=0.02, $sd$=0.14 |

- Experienced users made significantly more mistakes with the virtual laser pointer ($t$ = -4.521; $p$ <0.001) and tapping ($t$ = -2.145; $p$ = 0.035).
- No significant difference in mistakes made with d-pad selection ($t$ = 0.228; $p$ = 0.820).

### Performance Times by Menu Placement

| Menu Placement | Beginners | Experienced Users |
|---|---|---|
| World Space | $m$=17.84s, $sd$=8.34 | $m$=17.04s, $sd$=8.08 |
| Hand-mounted | $m$=13.77s, $sd$=3.52 | $m$=13.66s, $sd$=4.39 |
| HUD | $m$=15.48s, $sd$=4.46 | $m$=13.62s, $sd$=4.80 |

- No significant difference in performance times with any menu placement: world space menus ($t$ = 0.483; $p$ = 0.630), hand-mounted menus ($t$ = 0.111; $p$ = 0.912), heads-up display ($t$ = 1.906; $p$ = 0.060).

### Mistakes Made by Menu Placement

| Menu Placement | Beginners | Experienced Users |
|---|---|---|
| World Space | $m$=0.24, $sd$=0.60 | $m$=0.37, $sd$=0.66 |
| Hand-mounted | $m$=0.02, $sd$=0.10 | $m$=0.01, $sd$=0.08 |
| HUD | $m$=0.23, $sd$=0.48 | $m$=0.36, $sd$=0.59 |

- No significant difference in mistakes made with any menu placement: world space menus ($t$ = -0.942; $p$ = 0.349), hand-mounted menus ($t$ = 0.211; $p$ = 0.834), heads-up display ($t$ = -1.109; $p$ = 0.270).

**Performance Times by Navigation Method**

| Navigation Method | Beginners | Experienced Users |
|---|---|---|
| Joystick Navigation | $m$=42.06s, $sd$=9.05 | $m$=39.05s, $sd$=8.72 |
| Teleportation | $m$=59.40s, $sd$=13.63 | $m$=47.56s, $sd$=10.67 |

- No significant difference with joystick navigation ($t$ = 1.141; $p$ = 0.260).
- Experienced users significantly faster with teleporting ($t$ = 3.304; $p$ = 0.002).

## A.3 Preference

**SAM Pleasure Ratings for Selection Types**

| Selection Type | Beginners | Experienced Users |
|---|---|---|
| Laser Pointer | $m$=1.90, $sd$=1.62 | $m$=2.04, $sd$=1.77 |
| Tapping | $m$=1.71, $sd$=2.08 | $m$=1.86, $sd$=1.64 |
| D-pad | $m$=0.33, $sd$=1.93 | $m$=0.10, $sd$=2.06 |

- No significant difference in happiness with any selection method: virtual laser pointer ($t$ = -0.271; $p$ = 0.788), tapping ($t$ = -0.281; $p$ = 0.780), d-pad selection ($t$ = 0.400; $p$ = 0.691).

**SAM Arousal Ratings for Selection Types**

| Selection Type | Beginners | Experienced Users |
|---|---|---|
| Laser Pointer | $m$=1.71, $sd$=2.03 | $m$=1.69, $sd$=1.71 |
| Tapping | $m$=1.29, $sd$=2.70 | $m$=1.34, $sd$=2.16 |
| D-pad | $m$=-0.67, $sd$=0.90 | $m$=-0.59, $sd$=0.80 |

- No significant difference in excitement with any selection method: virtual laser pointer ($t$ = 0.046; $p$ = 0.963), tapping ($t$ = -0.086; $p$ = 0.932), d-pad selection ($t$ = -0.270; $p$ = 0.789).

**SAM Dominance Ratings for Selection Types**

| Selection Type | Beginners | Experienced Users |
|---|---|---|
| Laser | $m$=1.10, $sd$=2.36 | $m$=1.28, $sd$=2.43 |
| Tapping | $m$=2.35, $sd$=1.76 | $m$=1.97, $sd$=2.26 |
| D-pad | $m$=0.10, $sd$=2.43 | $m$=0.90, $sd$=2.40 |

- No significant difference in sense of control with any selection method: virtual laser pointer ($t$ = -0.262; $p$ = 0.794), tapping ($t$ = 0.639; $p$ = 0.526), d-pad selection ($t$ = -1.161; $p$ = 0.251).

**SAM Pleasure Ratings for Menu Placements**

| Menu Placement | Beginners | Experienced Users |
|---|---|---|
| World Space | $m$=1.10, $sd$=2.00 | $m$=1.38, $sd$=1.54 |
| Hand-mounted | $m$=1.62, $sd$=2.33 | $m$=1.45, $sd$=1.59 |
| HUD | $m$=-0.81, $sd$=2.27 | $m$=-0.52, $sd$=2.46 |

- No significant difference in happiness with any menu placement: world space menus ($t$ = -0.567; $p$ = 0.573), hand-mounted menus ($t$ = 0.290; $p$ = 0.774), heads-up display ($t$ = -0.428; $p$ = 0.670).

**SAM Arousal Ratings for Menu Placements**

| Menu Placement | Beginners | Experienced Users |
|---|---|---|
| World Space | $m$=0.33, $sd$=2.11 | $m$=0.45, $sd$=2.13 |
| Hand-mounted | $m$=0.86, $sd$=2.54 | $m$=0.86, $sd$=2.08 |
| HUD | $m$=1.33, $sd$=1.46 | $m$=0.52, $sd$=1.42 |

- No significant difference in excitement with any menu placement: world space menus ($t$ = -0.189; $p$ = 0.851), hand-mounted menus ($t$ = -0.008; $p$ = 0.994), heads-up display ($t$ = 1.945; $p$ = 0.058).

**SAM Dominance Ratings for Menu Placements**

| Menu Placement | Beginners | Experienced Users |
|---|---|---|
| World Space | $m$=2.80, $sd$=1.28 | $m$=2.57, $sd$=1.43 |
| Hand-mounted | $m$=2.43, $sd$=1.86 | $m$=1.79, $sd$=1.76 |
| HUD | $m$=-0.86, $sd$=2.57 | $m$=-0.31, $sd$=2.52 |

- No significant difference in sense of control with any menu placement: world space menus ($t$ = 0.571; $p$ = 0.571), hand-mounted menus ($t$ = 1.231; $p$ = 0.224), heads-up display ($t$ = -0.750; $p$ = 0.457).

**SAM Pleasure Ratings for Navigation Methods**

| Navigation Method | Beginners | Experienced Users |
|---|---|---|
| Joystick Navigation | $m$=1.38, $sd$=2.40 | $m$=1.38, $sd$=2.41 |
| Teleportation | $m$=3.37, $sd$=1.86 | $m$=2.61, $sd$=1.76 |

- No significant difference in happiness with joystick navigation ($t$ = 0.002; $p$ = 0.998).

- Beginners significantly happier when teleporting ($t$ = 2.036; $p$ = 0.048).

**SAM Arousal Ratings for Navigation Methods**

| Navigation Method | Beginners | Experienced Users |
|---|---|---|
| Joystick Navigation | $m$=2.05, $sd$=1.94 | $m$=0.97, $sd$=2.78 |
| Teleportation | $m$=3.28, $sd$=0.83 | $m$=2.73, $sd$=1.37 |

- No significant difference in excitement with either navigation technique: joystick navigation ($t = 1.621$; $p = 0.112$), teleportation ($t = 1.509$; $p = 0.139$).

**SAM Dominance Ratings for Navigation Methods**

| Navigation Method | Beginners | Experienced Users |
|---|---|---|
| Joystick Navigation | $m$=1.43, $sd$=2.69 | $m$=1.38, $sd$=2.58 |
| Teleportation | $m$=2.50, $sd$=1.50 | $m$=2.43, $sd$=1.77 |

- No significant difference in sense of control with either navigation technique: joystick navigation ($t = 0.065$; $p = 0.948$), teleportation ($t = 0.146$; $p = 0.884$).

# Appendix B Hypotheses Results

## B.1 Hypothesis 1

**Beginners' Performance Times by Selection Type**

| Selection Type | Results |
|---|---|
| Laser Pointer | $m$=13.19s, $sd$=4.25 |
| Tapping | $m$=11.27s, $sd$=4.40 |
| D-pad | $m$=18.86s, $sd$=5.28 |

**Beginners' Mistakes Made by Selection Type**

| Selection Type | Results |
|---|---|
| Laser Pointer | $m$=0.03, $sd$=0.17 |
| Tapping | $m$=0.37, $sd$=0.69 |
| D-pad | $m$=0.03, $sd$=0.16 |

**Beginners' SAM Pleasure Ratings for Selection Types**

| Selection Type | Results |
|---|---|
| Laser Pointer | $m$=1.90, $sd$=1.62 |
| Tapping | $m$=1.71, $sd$=2.08 |
| D-pad | $m$=0.33, $sd$=1.93 |

**Beginners' SAM Arousal Ratings for Selection Types**

| Selection Type | Results |
|---|---|
| Laser Pointer | $m$=1.71, $sd$=2.03 |
| Tapping | $m$=1.29, $sd$=2.70 |
| D-pad | $m$=-0.67, $sd$=0.90 |

**Beginners' SAM Dominance Ratings for Selection Types**

| Selection Type | Results |
|---|---|
| Laser Pointer | $m$=1.10, $sd$=2.36 |
| Tapping | $m$=2.35, $sd$=1.76 |
| D-pad | $m$=0.10, $sd$=2.43 |

## B.2 Hypothesis 2

**Experienced Users' Performance Times by Selection Type**

| Selection Type | Results |
|---|---|
| Laser Pointer | $m$=13.09s, $sd$=4.63 |
| Tapping | $m$=12.65s, $sd$=6.39 |
| D-pad | $m$=15.82s, $sd$=5.88 |

**Experienced Users' Mistakes Made by Selection Type**

| Selection Type | Results |
|---|---|
| Laser Pointer | $m$=0.47, $sd$=0.69 |
| Tapping | $m$=0.84, $sd$=1.16 |
| D-pad | $m$=0.02, $sd$=0.14 |

**Experienced Users' SAM Pleasure Ratings for Selection Types**

| Selection Type | Results |
|---|---|
| Laser Pointer | $m$=2.04, $sd$=1.77 |
| Tapping | $m$=1.86, $sd$=1.64 |
| D-pad | $m$=0.10, $sd$=2.06 |

**Experienced Users' SAM Arousal Ratings for Selection Types**

| Selection Type | Results |
|---|---|
| Laser Pointer | $m$=1.69, $sd$=1.71 |
| Tapping | $m$=1.34, $sd$=2.16 |
| D-pad | $m$=-0.59, $sd$=0.80 |

**Experienced Users' SAM Dominance Ratings for Selection Types**

| Selection Type | Results |
|---|---|
| Laser Pointer | $m$=1.28, $sd$=2.43 |
| Tapping | $m$=1.97, $sd$=2.26 |
| D-pad | $m$=0.90, $sd$=2.40 |

## B.3 Hypothesis 3

**Performance Times by Menu Placement**

| Menu Placement | Results |
|---|---|
| World Space | $m$=17.38s, $sd$=8.16 |
| Hand-mounted | $m$=13.71s, $sd$=4.03 |
| HUD | $m$=14.38s, $sd$=4.73 |

**Mistakes Made by Menu Placement**

| Menu Placement | Results |
|---|---|
| World Space | $m$=0.32, $sd$=0.64 |
| Hand-mounted | $m$=0.02, $sd$=0.13 |
| HUD | $m$=0.31, $sd$=0.55 |

**SAM Pleasure Ratings for Menu Placements**

| Menu Placement | Results |
|---|---|
| World Space | $m$=1.26, $sd$=1.74 |
| Hand-mounted | $m$=1.52, $sd$=1.92 |
| HUD | $m$=-0.64, $sd$=2.36 |

**SAM Arousal Ratings for Menu Placements**

| Menu Placement | Results |
|---|---|
| World Space | $m$=0.40, $sd$=2.10 |
| Hand-mounted | $m$=0.86, $sd$=2.26 |
| HUD | $m$=0.88, $sd$=1.48 |

**SAM Dominance Ratings for Menu Placements**

| Menu Placement | Results |
|---|---|
| World Space | $m$=2.67, $sd$=1.36 |
| Hand-mounted | $m$=2.06, $sd$=1.81 |
| HUD | $m$=-0.54, $sd$=2.53 |

## B.4 Hypothesis 4

**Beginners' Performance Times by Navigation Method**

| Navigation Method | Results |
|---|---|
| Joystick Navigation | $m$=42.06s, $sd$=9.05 |
| Teleportation | $m$=59.40s, $sd$=13.63 |

**Beginners' SAM Pleasure Ratings for Navigation Methods**

| Navigation Method | Results |
|---|---|
| Joystick Navigation | $m$=1.38, $sd$=2.40 |
| Teleportation | $m$=3.37, $sd$=0.76 |

**Beginners' SAM Arousal Ratings for Navigation Methods**

| Navigation Methods | Results |
|---|---|
| Joystick Navigation | $m$=2.05, $sd$=1.94 |
| Teleportation | $m$=3.28, $sd$=0.83 |

**Beginners' SAM Dominance Ratings for Navigation Methods**

| Navigation Method | Results |
|---|---|
| Joystick Navigation | $m$=1.43, $sd$=2.69 |
| Teleportation | $m$=2.50, $sd$=1.50 |

## B.5 Hypothesis 5

**Experienced Users' Performance Times by Navigation Method**

| Navigation Method | Results |
|---|---|
| Joystick Navigation | $m$=39.05s, $sd$=8.72 |
| Teleportation | $m$=47.56s, $sd$=10.67 |

**Experienced Users' SAM Pleasure Ratings for Navigation Methods**

| Navigation Method | Results |
|---|---|
| Joystick Navigation | $m$=1.38, $sd$=2.41 |
| Teleportation | $m$=2.61, $sd$=1.75 |

**Experienced Users' SAM Arousal Ratings for Navigation Methods**

| Navigation Method | Results |
|---|---|
| Joystick Navigation | $m$=0.97, $sd$=2.78 |
| Teleportation | $m$=2.73, $sd$=1.37 |

**Experienced Users' SAM Dominance Ratings for Navigation Methods**

| Navigation Method | Results |
|---|---|
| Joystick Navigation | $m$=1.38, $sd$=2.58 |
| Teleportation | $m$=2.43, $sd$=1.77 |

## B.6 Hypothesis 6

**SAM Comfort Ratings for Navigation Methods**

| Navigation Method | Results |
|---|---|
| Joystick Navigation | $m$=1.14, $sd$=2.81 |
| Teleportation | $m$=2.70, $sd$=1.40 |

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